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13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking Institute of Applied Science as follows: The contractor will investigate the possibility of lasing without inversion for gamma-ray as described in his proposal.

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Final report
Lasing Without Inversion in Gamma-Ray Range

This investigation involved three following directions.

1. THE COMPARATIVE ANALYSIS OF THE BASIC SCHEMES for inversionless amplification with respect to specific application in gamma-ray range. Search for the appropriate nuclear structure with the split operating levels and for the methods of the coherence excitation available in nuclei.
2. THE POSSIBILITIES OF THE MANIPULATIONS BY THE ABSORPTION-REFRACTIVE PROPERTIES of the multilevel quantum systems via driving of some resonant transitions by the strong coherent fields. Such possibilities are of interest not only for realization of amplification without inversion (via suppression of the resonant absorption) but also for the achievement of the high refraction index under conditions of the vanishing absorption what could provide, in principle, the high refractivity for radiation in gamma-range.
3. THE FUNDAMENTAL THERMODYNAMIC RESTRICTIONS inherent to the process of amplification without inversion.

The major results are as follows.

1. THE COMPARATIVE ANALYSIS OF THE BASIC SCHEMES The comparative analysis of three basic schemes for inversionless amplification (so called P-scheme, h-scheme and double-lambda scheme) which have been already realized experimentally in optical range was done with an emphasis on the possible application and specific features of these schemes in gamma-ray range.

   1.1. The nuclear coherence at Zeeman and hyperfine transitions can be excited by the resonant driving of these transitions with the microwave fields (using so-called P and h configurations). It is shown that this method can be applied only in case of the metastable upper operating level. For solids the corresponding life time should exceed milliseconds.

   1.2. New kind of the so-called combined P-h and double-lambda schemes, where nuclear coherence is excited by means of coherent laser fields acting at the resonant electron transitions due to the hyperfine interaction coupling electron and nuclear degrees of freedom, is suggested. In these schemes no restriction on the life time of the operating transition appears but the efficiency of the nuclear coherence excitation is decreased by the large factor which is a ratio of the frequencies of the operating gamma and adjacent optical transitions.

   1.3. The simplest five-level scheme involving eigenstates of the Hamiltonian of the combined coupled system: nuclei + electrons was suggested and analysed in details both analitically and numerically. The possibility of amplification without inversion in gamma-ray range on the basis of this scheme was demonstrated. The concrete estimates of the magnitude of the gain and the power of the incohernet and coherent pumping were given.

   (See refs. 1, 5, 9 below.)

2. THE POSSIBILITIES OF THE MANIPULATIONS BY THE ABSORPTION-REFRACTIVE PROPERTIES

   2.1. We analyzed three-level systems driven by the strong coherent field at one of three transitions and probed at the adjacent transition and shown that population trapping to one of two dressed states provides the high ratio of the refractive index to the absorption coefficient.

2.2. Such trapping can be achieved via two different mechanisms: either due to the large detuning of the driving field corresponding to the value of the Rabi frequency for the probe field or due to the crossing between one of two dressed states and a nearby unperturbed level leading to the drastic modification of the relaxation coefficients by the driving field.

2.3. The possibility of population inversion both at the driven and the adjacent higher frequency transitinons was demonstrated in the certain domain of intensity and detuning of the driving field.

2.4. Population trapping to the intermediate atomic level was predicted in case of sufficiently large intensity, which provides a new technik of optical pumping.

(See refs. 2-4, 8,10,11,13 below.)

3. THE FUNDAMENTAL THERMODYNAMIC RESTRICTIONS

3.1. We derived the general necessary condition of amplification without inversion for all four basic schemes involving three-four-level media driven by the resonant external coherent fields and probed at the adjacent transitions.

3.2. Analyzing this condition we strictly proved that independently on the intensity of the driving field amplification of the probe field in case of high frequency up-conversion from the driving to the probe field (with a conversion factor larger than 2) requires the presence of the inequilibrium reservoir providing incoherent pumping to the upper operating level.

3.3. The possibility of amplification with an up-conversion factor lower that 2 in case of thremally equilibrium reservoir was demonstated, which can provide the essentially new source of coherent radiation.

(See refs. 6, 7,12 below.)

These results were presented in the following papers:

1. O. Kocharovskaya and P. Mandel, Lasing Without Inversion: Progress and Prognosis, in: Coherent Phenomena and Amplification Without Inversion, Proc. SPIE 2897, eds. A.A. Andreev, O. Kocharovskaya and P. Mandel. P.190-197 (1996).
2. Y.V. Radeonychev, P. Mandel and O. Kocharovskaya, Influence of Field-Dependent Relaxation on Amplification Without Inversion , ibid. P.250-259.
3. M. Louffler, D. Nikonov, O. Kocharovskaya and M. O. Scully, High index of refraction for a steady field via dressed state selectivity, ibid. P.317-325.
4. M. Louffler, D. Nikonov, O. Kocharovskaya and M. O. Scully, High field index enhancment via selective population of dressed states, submitted to Phys. Rev.A.
5. O. Kocharovskaya, Prospects for realization of amplification without inversion in gamma-ray range, in: Proc. of the International Symposium on Atomic Coherence and Inversionless Amplification, eds. J.-Y. Gao and Shi-Yao Zhu, P. (1996).
6. O. Kocharovskaya and Yu. Rostovtsev, Thermodynamic restrictions on amplification without invsersion, in: Nonlinear waves. Synchronization and Patterns. Part 2. eds. Rabinovich M.I., Sushchik M.M. and Shalfeev V.D.. Nizhny Novgorod University Press. P.31-37 (1996).
7. O. Kocharovskaya, Yu. Rostovtsev and A. Imamoglu, Anti-Stokes component amplification in three-level atoms coupled with a thermal equilibrium reservoir, Technical digest of the European Quantum Electronics conference (Hamburg, 8-13 September, 1996), P.95.
8. O. Kocharovskaya, P. Mandel and Y.V. Radeonychev, ibid. P.103.

9. O. Kocharovskaya, Lasing without iniversion: problems and prospects , Proceedings of the 1st International Gamma-ray Laser Workshop, Predeal, Romania, 19-23 August,P.187, 1995.

10. O.Kocharovskaya, P.Mandel, Atomic coherence and field-dependent relaxation in strongly driven three-level atoms, J.Tech.Phys., 1997, v.38, N2 pp.235-237.

11. Y.V. Radeonychev, O. Kocharovskaya, Anomalous response of strongly driven three-level atoms resulting from field-modified spontaneous relaxation, Technical digest of the 1997 Quantum Electronics and Laser Science conference (QELS'97), Baltimore, 18-23 May, 1997.

12. Yu. Rostovtsev, A.Imamoglu and O. Kocharovskaya ibid. P.

13. O.Kocharovskaya and Y.V. Radeonychev, Spontaneous emission from the ground atomic state due to its crossing with the dynamic Stark level, Found. of Phys. submitted.

These results were presented at

1. 5th International workshop on Laser Physics (LPHYS'96), invited paper, Moscow, July 1996,
2. European conference on Quantum Electronics, two oral papers, Hamburg, September 1996,
3. Quantum Electronics and Laser Science conference (QELS'97), Baltimor, May 1997 and at the seminar "Lasers without inversion: mastering of the new frequency ranges" at Max-Planck Institute fur Quantum Optik, Garching, July 1996.

They will be presented also at

1. International Symposium on Photon Echo and coherent spectroscopy (R.Kolesov, Yu.Rostovtsev and O. Kocharovskaya Ioshkar-Ola, June, 1997) , accepted
2. Internatinal conference on Induced gamma-ray radiation, Predeal,August,1997 (Yu. Rostovtsev, R. Kolesov and O. Kocharovskaya,) accepted.